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REPORT

Colour film telerecording using a shadow-mask display tube

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(PH-77)

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Summary

The development of shadow-mask tubes with increased luminance has justified an investigation into the feasibility of using such a display in colour-film telerecording equipment. This would represent a considerably simplification over an earlier colour telerecording proposal in which a system of dichroic mirrors superimposed the displays from three separate cathode ray tubes, each carrying a single display primary.[1,2] *Owing to the nature of the shadow-mask display, optical filters cannot be used to modify the spectral characteristics of the individual phosphors in order to minimise the degree of 'cross-talk' occurring within the film. This problem is discussed, together with the limitations on the maximum luminance of the display. It is concluded that satisfactory colorimetric results can be obtained with the phosphors and film considered; an adequate exposure for colour negative film would be provided by an f/1·4 camera lens.*

1. Introduction

Shadow-mask tubes are now being manufactured with a black opaque matrix covering the area between the phosphor dots. The matrix absorbs ambient light without reducing the light output from the phosphor-dot screen. This enables the transmission of the faceplate to be made greater than that of the conventional tube and the consequent increase in the luminance of the display permits picture contrast to be preserved, even under relatively high ambient light conditions.

The purpose of the investigation was to assess whether or not the increased display luminance provided by a modern black-matrix tube (e.g. RCA 25BDP22) would satisfactorily expose colour negative film (e.g. Eastman Kodak type 7254). The degree of cross-talk within the film was also evaluated, and an attempt was made to minimise this by electronically correcting the tube input signals.

2. Factors affecting the quality of the telerecording

There are certain factors common to any telerecording system which must be carefully controlled in order to achieve acceptable results; these are discussed below.

2.1. Correct exposure of the film

The transfer characteristic of negative colour film is usually represented by its D/log E curves;* a typical example of one curve is illustrated in Fig. 1. It is important that the exposure of the film in the camera be such that the film densities produced by the shadow-mask tube display lie along the linear parts of the characteristics (i.e. between points such as A and B).

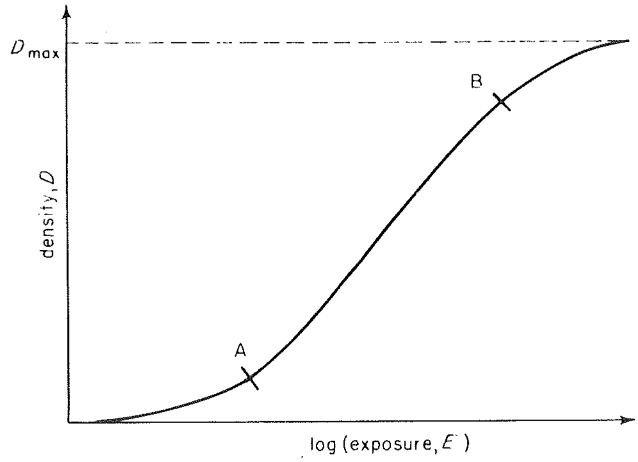

Fig. 1 - A D/log E curve

Assuming that the telerecording camera exposes each frame of the film to two television fields and knowing the maximum and minimum display luminances, it is possible to determine the lens aperture which allows operation over the linear parts of the D/log E curves.

2.2. Colour distortion effects caused by cross-talk within the negative

The spectral analysis of the original scene into its red, green and blue components is defined by the colorimetric requirements of the phosphors used in the final display (i.e. the viewer's receiver) and this analysis is carried out by the television camera. In a telerecording process the three photo-sensitive layers of the colour negative are desirably regarded as independent recording media, each storing information from one of the three phosphors used in the telerecording display. However, cross-talk does occur between the red, green and blue signals due to the 'broad-band' nature of both the spectral emission characteristics of the telerecording phosphors and the spectral sensitivities of the individual layers in the negative, and this, ideally, must be eliminated if the signals to be obtained by replaying the telerecording in a high-quality telecine machine are to provide pictures with good colour fidelity.

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* A D/log E curve is obtained by plotting the optical density of the developed film against the logarithm of the time-intensity product representing exposure.

3. Problems of using a shadow-mask display tube

A feasibility study was made five years ago into the design of a high-quality colour telerecording system.[1,2] The most promising approach used three cathode-ray tubes, one for each of the red, green and blue 'channels'. A system of mirrors was used to combine the pictures from the three tubes, the final display being much brighter than that obtainable with a shadow-mask tube. This arrangement also allowed optical shaping filters to be interposed between the individual phosphors and the combining mirrors in order suitably to narrow their spectral emission characteristics. In this way the cross-talk within the film could be reduced to a very low level.

The limitations imposed by the shadow-mask tube have since become less with the advent of brighter tubes and a possible method for correcting the cross-talk is outlined below.

3.1. Maximum display luminance

The maximum display luminance is limited by beam defocusing which occurs when the beam current of one or more of the tube electron-guns becomes too high. Before determining the maximum luminance permissible for white, the colour temperature of the display must be adjusted to a correlated colour temperature of 3,200°K in order to provide a correct white-point match with film such as Eastman Negative Film Type 7254. This condition defines the relative values of the red, green and blue beam currents in the tube; thus the picture component corresponding to the largest of the three is likely to be the first to defocus as the luminance is increased. The relative luminances of the red, green and blue phosphor displays necessary to obtain a colour temperature of 3,200°K were calculated and details of this calculation are outlined below.

Curves were available showing the relative response of each dye-forming layer to a blackbody radiator at 3,200°K; the area under each of these curves was calculated and their ratio noted. A spectrometer was used to measure the spectral characteristics of the individual phosphors and the normalised versions of these curves are shown in Fig. 2. To secure a correct white in the telerecording, the red, green and blue phosphors must each produce responses in the cyan, magenta and yellow dye-forming film layers respectively in the same ratio as those produced by a black body at 3,200°K. The response to the normalised characteristics of Fig. 2 were evaluated initially and a multiplication factor was then obtained* for the ordinates of each

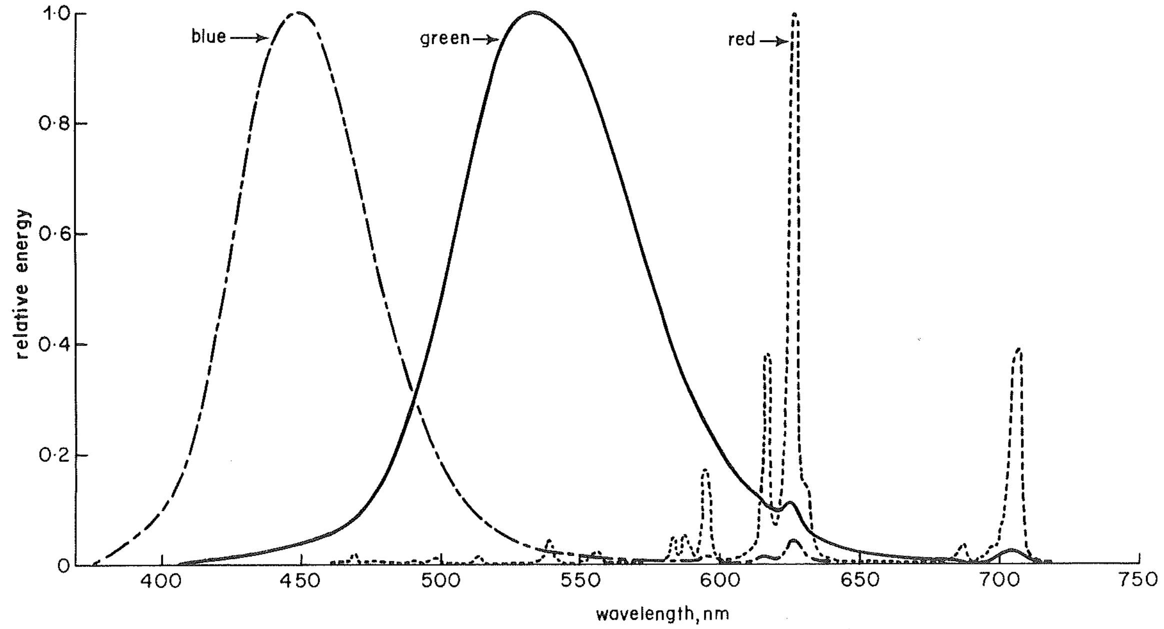

Fig. 2 - Normalised spectral characteristics of the display phosphors

normalised phosphor characteristic which would ensure that the relative exposures produced by the three phosphors would be the same as those produced by the blackbody at 3,200°K. For the phosphors used, these multiplication factors were 29 for the red phosphor, 2 for the green phosphor and unity for the blue phosphor (the latter was used as the reference). The relative luminances represented by these modified phosphor characteristics were calculated* and are shown in Table 1.

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* The absolute spectral sensitivities of each dye-forming layer were known, and for the purposes of this calculation it was assumed that cross-talk did not occur. The normalised characteristic for the red phosphor was multiplied by the absolute sensitivity of the cyan forming layer and the area under the resulting curve was evaluated. The same procedure was adopted for the green phosphor and magenta forming layer, also the blue phosphor and the yellow forming layer. The ratio of the three resulting areas represented normalised relative exposures of the three layers and these were compared with those computed for the blackbody radiator. The multiplication factors derived from this comparison were used to equalise exposures for both cases.

TABLE 1

Ratio of Phosphor Luminances Required for a Recorded White Colour Temperature of 3,200°K

Red	Green	Blue
0·53	1	0·06

Adjustment of the relative luminances of the phosphors was carried out with input R, G and B signals representing a neutral grey, and since these signals normally have equal amplitudes, attenuators were included in two of the input signal paths in order to obtain the luminance ratios shown in Table 1. Phosphor efficiencies were such that the red signal carried the largest fraction of the total beam current and the maximum luminance of the display was therefore related to the level at which the red phosphor exhibited defocusing effects. The maximum display luminance corresponding to a white signal, together with the phosphor luminances and associated beam currents, is shown in Table 2.

TABLE 2

Maximum Phosphor Luminances and Associated Beam-Currents

Phosphor	Luminance (Indicated Foot Lamberts on Meter)	Beam-Current μA
Red	8·8	220
Green	15·2	57
Blue	1	30
Total	25	307

It must be emphasised that the figures shown in Table 2 were obtained with equipment available at the time of the experiment. It might have been possible to obtain a greater luminance using a specially developed display monitor.

3.2. Matrix correction for film cross-talk

Since the spectral sensitivities of the dye-forming layers in a film cannot be changed, and access to the individual display phosphors with optical filters is not possible, a possible way to minimise the film cross-talk is to use electronic correction in the form of a matrix applied to the red, green and blue display monitor input signals. The derivation of this matrix is described below, but, owing to practical difficulties, its implementation must be accepted as a compromise.

The response of all three dye-forming layers to each of the red, green and blue phosphors must be calculated. As described earlier, this involves taking the absolute sensitivities of the dye-forming layers and multiplying each by the emissions of each phosphor in turn, the latter being scaled by their appropriate multiplication factors. The resulting response curves are then integrated and the answers expressed in the form of three simultaneous equations. Typical results (for RCA Tube Type 25BDP22 with Eastman Negative Film Type 7254) are shown below. There is one equation for each phosphor and the coefficients preceding the Y, M and C represent the relative responses of the yellow, magenta and cyan dye-forming layers respectively.

Red phosphor $R = 1C + 0{\cdot}124M + 0{\cdot}001Y$
Green phosphor $G = 0{\cdot}082C + 1M + 0{\cdot}142Y$
Blue phosphor $B = 0{\cdot}001C + 0{\cdot}033M + 1Y$

It will be seen that the cross-talk for the phosphor and film combination under investigation is quite small.

The three equations above can be represented in matrix form as follows:

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix} \begin{bmatrix} C \\ M \\ Y \end{bmatrix}$$

Denoting the coefficient matrix by X, the above can be written

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = X \begin{bmatrix} C \\ M \\ Y \end{bmatrix} \text{ and therefore } \begin{bmatrix} C \\ M \\ Y \end{bmatrix} = X^{-1} \begin{bmatrix} R \\ G \\ B \end{bmatrix} \text{ where } X^{-1} = \frac{\text{adj. } X}{|X|}$$

The inverse matrix, X^{-1}, is the one which should be applied to the input signals in order to minimise the cross-talk; it was evaluated for the above coefficients with the following results:

$$\begin{bmatrix} C \\ M \\ Y \end{bmatrix} = \begin{bmatrix} 1{\cdot}01 & -0{\cdot}129 & 0{\cdot}018 \\ -0{\cdot}085 & 1{\cdot}034 & -0{\cdot}151 \\ 0{\cdot}002 & -0{\cdot}035 & 1{\cdot}033 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

where R, G and B represent the red, green and blue signal amplitudes.

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* The spectral-sensitivity curve of the photometer used in the tests had been previously measured and was multiplied by each of the phosphor characteristics in turn. The results of these multiplications were integrated with respect to wavelength and the ratio of the values of the three integrals gave the ratio of the phosphor luminances (as measured by the meter) required to obtain a display of correct colour temperature.

This method of correction requires that the matrix must operate on linear signals. However, in a practical case the input signals are gamma-corrected and to transform them to linear versions for matrixing, and to gamma-correct before applying them to the monitor would not be considered worthwhile.

Ideally, no relative gain changes between the three signals should be made after the matrix; it must perform its corrections on the signals which actually drive the tube. The matrix will not function correctly on signals which have quite different amplitudes when representing a neutral grey on the display, and its effectiveness in this respect is further complicated by the fact that, as computed from the phosphor and film characteristics, it is a non-unity matrix. It was realised that any form of matrix correction would only represent an approximation to the ideal solution; a compromise was therefore adopted.

It was decided to use a unity matrix on the input signals before the relative signal amplitudes were balanced for the correct display colour temperature. The matrix could therefore operate on signals which have equal amplitudes for a neutral grey. The coefficients in each row of the computed matrix were normalised to a unity form, and the final version used for experimental purposes is shown below:

$$\begin{bmatrix} C \\ M \\ Y \end{bmatrix} = \begin{bmatrix} 1{\cdot}12 & -0{\cdot}14 & 0{\cdot}02 \\ -0{\cdot}11 & 1{\cdot}3 & -0{\cdot}19 \\ 0 & -0{\cdot}04 & 1{\cdot}03 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

This is an approximation, but it appears to represent the only really practicable form of correction.

4. Experimental method

4.1. Display luminance and exposure tests

A 25-inch version of the black-matrix tube was used for the display together with a high quality commercial monitor chassis. The tube E.H.T. voltage was provided by an external stabilised supply. A 35 mm still camera with an f/1·4 lens was used to photograph the display. In order to simulate a telerecording camera, electronic switches were placed in each of the three signal paths. These switches would normally be open but, when triggered by the camera shutter, they allowed information corresponding to two successive television fields to be applied to the tube. Each frame of the film therefore recorded one complete television picture and received the same exposure as would the film in a telerecording camera with the same lens aperture.

The photographs taken explored the whole range of the film transfer characteristic. For this purpose a seven-step grey scale was used, the bottom and top steps corresponding to black level and white level respectively. Photographs were taken with lens apertures of f/1·4, f/2·8 and f/4, maximum display luminance being used for the white signal. The total luminance of each step in the grey scale was measured, together with the luminances of the individual phosphors. These are shown in Table 3 below.

A densitometer was used to measure the dye density in each step of the grey scale in the processed negative film. The spectral analysis characteristics of the densitometer could be varied to measure the density of each dye-forming layer substantially independently. Knowing the luminance of the display and the lens aperture employed, the exposure of the film for each step was calculated. These readings were used to plot the D/log E curves for each of the dye-forming layers.

4.2. Cross-talk measurement

In order to measure the cross-talk the step wedge was applied to each gun separately with, in each case, the other two guns driven by a fixed signal corresponding, in level, to the middle step of the wedge. If there is no cross-talk then there will be no step wedge information in the corresponding two layers of the negative; step wedge information in these two layers is thus a measure of the cross-talk. The reason for exposing the layers uniformly is to ensure that any cross-talk is superimposed on straight sections of the D/log E characteristics and is not concealed by non-linearity at low exposures.

The cross-talk was measured by placing the processed negative in a flying spot scanner, provided with masking, so that the information recorded in each layer could be examined separately.

TABLE 3

Phosphor Luminances in the Seven-Step Grey Scale

Phosphor	Luminance (Indicated Foot-Lamberts on Meter)						
	White						Black
	1	2	3	4	5	6	7
Red	8·8	7·4	3·6	2·3	0·9	0·37	0·04
Green	15·2	13·5	6·8	4	1·4	0·47	0·03
Blue	1	0·9	0·4	0·2	0·1	0·02	0
Total	25	21·8	10·8	6·5	2·4	0·86	0·07

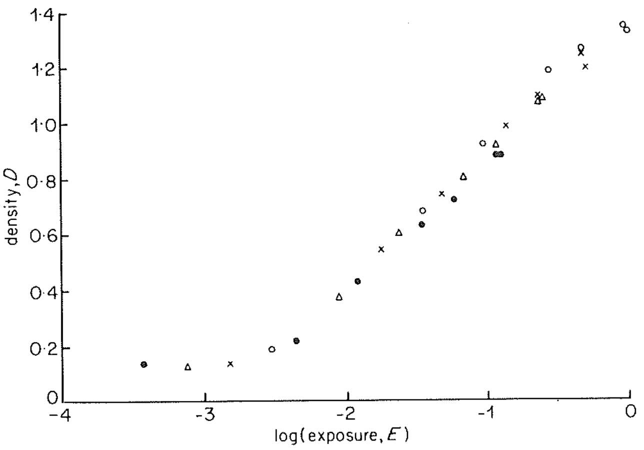

Fig. 3 - Transfer characteristic of the cyan dye-forming layer

○ f1·4 × f2 △ f2·8 ● f4

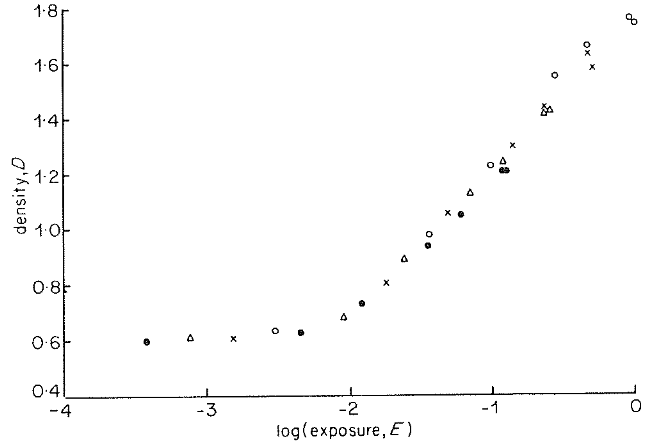

Fig. 4 - Transfer characteristic of the magenta dye-forming layer

○ f1·4 × f2 △ f2·8 ● f4

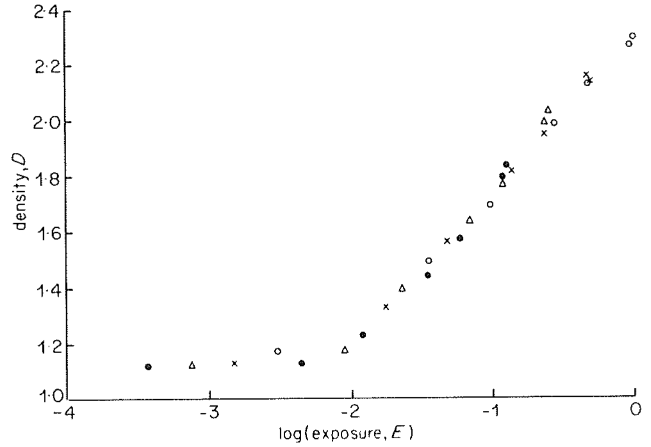

Fig. 5 - Transfer characteristic of the yellow dye-forming layer

○ f1·4 × f2 △ f2·8 ● f4

5. Results

Figs. 3, 4 and 5 illustrate the transfer characteristics (i.e. D/log E curves) obtained from the density measurements for the cyan, magenta and yellow dye-forming layers respectively. The range of film densities produced by a particular lens aperture is easily identified. In every case it will be noted that in order to operate on the linear portion of these characteristics a lens aperture of f/1·4 was required. Smaller apertures would result in information being lost due to the reduced gradient of the curve at low light-levels.

The cross-talk tests confirmed previous deductions that the cross-talk in the film was insignificant without the matrix. Exposures taken with the matrix did not show any significant improvement.

6. Conclusions

With the phosphor and film combination used in this investigation, satisfactory colour telerecordings should be possible with an f/1·4 camera lens. Matrix correction is not essential, although this technique could prove useful if the phosphor and film characteristics were such as to generate a higher degree of film cross-talk.

A suitably designed display monitor could permit the use of an increased maximum display luminance without degrading the definition of the picture.

7. Acknowledgements

The author acknowledges the assistance given by Dr. F. Gloyns of Rank Denham Laboratories Limited in processing the film used in this investigation.

8. References

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